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Brightness and Spatial Resolution of a Prototype, Green-Laser Projector Measured for Various Display Screens and Image Sizes

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14. ABSTRACT

Laser light has many unique characteristics, such as coherence and speckle, and in addition, the individual pixels formed by the raster structure of a laser projector have very little persistence. As a result, there is some question as to whether the luminance of laser-projector imagery can be measured accurately, and whether that imagery will appear the same as more conventional imagery of the same luminance. In a preliminary attempt to address these questions, we have measured the luminance of a cathode ray tube (CRT) and a laser projector and have directly compared their measured luminance and perceived brightness. There were no apparent difficulties or complications in measuring the luminance of the laser projector using a standard spotmeter. However, a laser-projector image judged to have the same brightness as a CRT image had a measured luminance that was about 14% less. Thus, the limited and preliminary data reported here indicate that a laser image of the same luminance appears slightly brighter than that of a CRT. There were some differences between the CRT and laser measurements made with a spotmeter and with a CCD photometer. Although the differences were relatively small for display luminances less than about 5 fL, this issue should be addressed further with future versions of the laser projector. There appears to be a real difference in the spatial resolution measured at the center and edge of imagery projected onto the three screen tested. However, given the variability of the measurements, there is no clear evidence of significant differences among the three screens tested in center-to-edge spatial resolution. The relatively small (5.5% overall) reduction in spatial resolution as projected image size was reduced represents an apparent advantage of the laser projector over other displays. Further data are needed, however, to determine if this reduction in spatial resolution is significantly greater at the edge of the image.

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BRIGHTNESS AND SPATIAL RESOLUTION
OF A PROTOTYPE, GREEN-LASER PROJECTOR MEASURED
FOR VARIOUS SCREENS AND IMAGE SIZES

SUMMARY

There were no apparent difficulties or complications in measuring the luminance of the laser projector using a standard spotmeter. However, a laser-projector image judged to have the same brightness as a cathode ray tube (CRT) image had a measured luminance that was about 14% less. Thus, the limited and preliminary data reported here indicate that a laser image of the same luminance appears slightly brighter than that of a CRT.

There were some differences between the CRT and laser measurements made with a spotmeter and with a CCD photometer (Figure 1). Although the differences were relatively small for display luminances less than about 5 fL, this issue should be addressed further with future versions of the laser projector.

There appears to be a real difference in the spatial resolution measured at the center and edge of imagery projected onto the three screen tested (Table 1). However, given the variability of the measurements, there is no clear evidence of significant differences among the three screens tested in center-to-edge spatial resolution.

The relatively small (5.5% overall) reduction in spatial resolution as projected image size was reduced (Table 2) represents an apparent advantage of the laser projector over other displays. Further data are needed, however, to determine if this reduction in spatial resolution is significantly greater at the edge of the image.

I. LUMINANCE / BRIGHTNESS COMPARISON

BACKGROUND / INTRODUCTION

Laser light has many unique characteristics, such as coherence and speckle, and in addition, the individual pixels formed by the raster structure of a laser projector have very little persistence. As a result, there is some question as to whether the luminance of laser-projector imagery can be measured accurately, and whether that imagery will appear the same as more conventional imagery of the same luminance. In a preliminary attempt to address these questions, we have measured the luminance of a CRT and a laser projector and have directly compared their measured luminance and perceived brightness.

METHOD

For the luminance / brightness comparison, test images (1920 × 1080 pixels) were displayed using either an Evans & Sutherland laser projector prototype (green channel only) or a Sony color CRT monitor. To facilitate comparison with the laser projector, only the green channel of the CRT monitor was used. The laser image was displayed on a Proscreen 1.2 rear-projection screen. Luminance measurements were made with a Minolta Model LS-100 spotmeter and a CCD camera (SBIG, Inc., Model ST-7). The two devices were set up so as to view a 5 × 3.5 cm area near the center of each display, at an angle of about 20° from normal to the display screens.

Four observers sequentially viewed various gray-levels on the CRT monitor and chose the one that best matched the highest gray-level (255) displayed on the laser projector.

RESULTS

Gamma functions for the CRT and laser projectors are shown in Figure 1. Both functions have the general form of an expansive power function, although the luminance of the laser projector was less than that of the CRT for all gray-levels (i.e., 8-bit DAC values) tested.

Shown in Figure 2 is the relationship between luminance, as measured by the spotmeter, and CCD output for both the laser projector and the CRT monitor. The two straight lines shown in the figure were fit to the data sets using a least-squares criterion. Although there is little difference in the data for luminances below about 5 fL, there is some indication of more significant differences at higher luminance levels.

The four observers who visually matched the brightness of the CRT and laser displays, on average, required a CRT luminance of 8.8 fL to match a laser luminance of 7.7 fL.

CONCLUSIONS AND RECOMMENDATIONS

There were no apparent difficulties or complications in measuring the luminance of the laser projector using a standard spotmeter. However, a laser-projector image judged to have the same brightness as a CRT image had a measured luminance that was about 14% less. Thus, the limited and preliminary data reported here indicate that a laser image of the same luminance appears slightly brighter than that of a CRT.

There were some differences between the CRT and laser measurements made with a spotmeter and with a CCD photometer (Figure 2). Although the differences were relatively small for display luminances less than about 5 fL, this issue should be addressed further with future versions of the laser projector.

Finally, it should be noted that the spectral properties of the CRT and the laser projector are not identical in that the laser output has a slightly lower peak wavelength and a much smaller spectral bandwidth. Either or both of these differences may have contributed to the relatively small differences in luminance and perceived brightness reported here. The spectral differences between the two devices may have to be considered if small differences in perceived brightness are deemed important in future applications of the laser projector.

II. SCREEN-LOCATION / IMAGE-SIZE COMPARISONS

BACKGROUND / INTRODUCTION

Several rear-projection screens are being considered for use with the laser projector under development at the Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Readiness Research Division (AFRL/HEA). Rear-projections screens are known to have different directional properties that might affect the relative appearance of imagery presented at the center and in the periphery of a wide-field display. The directional properties of three rear-projection screens have been assessed to determine if those properties differ among the screens, and if any difference might have significant effects on projected image quality.

The directional properties mentioned above may also vary as projected image size is changed. Image size might be changed, for instance, when several images are tiled to increase spatial resolution. However, reducing image size may itself decrease spatial resolution. To begin to address this issue, we have measured spatial resolution for laser-projector image sizes differing by a factor of two.

METHOD

Three rear-projection screens were evaluated: a Proscreen 1.2, a Stewart Blackhawk, and a Jenmar Blackscreen. The screens were placed at either 68.3 cm or 180.1 cm from a prototype, green-laser projector resulting in a projected horizontal image size of either 61.3 cm or 122.4 cm, respectively. The image sizes resulted in single-pixel line widths of 0.24 mm and 0.12 mm, respectively. The projector was driven by four PC-IG channels which together provided a 5120 × 1024 pixel image. There was some jitter (approximately 2 Hz, lateral motion) in the projected image, which undoubtedly reduced the measured spatial resolution. This reduction in resolution did not however affect the relative measurements upon which the current conclusions are based.

Spatial resolution measurements were made with either an SBIG-Model ST-7 or an IQCam-Model 3 CCD-based photometer Spatial resolution was estimated using a technique similar to that suggested in the *VESA Flat Panel Display Measurements Standard*, v.2.0, June 2001.

RESULTS

The relationship between input gray-level and output luminance (i.e., the gamma function) is shown in Figure3 for three laser projector measurements made over a period of about five months. All functions are similar in form, although the maximal laser output varied by about 20% over the period sampled.

Shown in Figure 4 is the change in luminance with viewing angle for the laser projector as used with the Proscreen 1.2 and Stewart Blackhawk rear-projection screens. The fall-off in luminance is slightly greater and somewhat more symmetrical for the Stewart Blackhawk screen.

The spatial resolution estimates obtained for all three screens, both image sizes (small and large), and both screen locations (center, edge) are shown in Tables 1 and 2. The ratio of spatial resolution at the center of the screen to spatial resolution at the edge of the screen (i.e., the center to edge ratio) is shown in Table 1 for all three screens. Although the spatial resolution estimates vary across the different testing dates, the center to edge ratio remains nearly constant between 1.06 and 1.09. These data indicate that spatial resolution is 6-9% greater at the center than at the edge. It should be noted that this 6-9% difference applies to the projector-screen combination, as we have not determined how the projector image changes with location independently of the projection screens.

Spatial resolution of the large and small images projected at the center and edge of the Proscreen 1.2 screen are shown in Table 2. At the center of the projected image, there was virtually no difference in spatial resolution for the two image sizes (large to small ratio = 1.01). There was a much larger large to small ratio (1.11) for the spatial resolution measurements made at the edge of the screen. It should be noted that the edge data are based on only a single measurement. However, given the projection optics of the laser projector (or any projector, for that matter) it might be expected that edge resolution would change more with image size because reducing image size increases the proportion of off-axis light that is projected.

CONCLUSIONS AND RECOMMENDATIONS

The variability in the center to edge spatial resolution measurements may be due in part to changes in the properties of the laser projector image over time, variations in the laser focus adjustments (which were done visually), and the measurement error of the CCD camera. Although the data are not sufficient for a complete statistical analysis, there appears to be a consistent and real difference in the center to edge ratio of spatial resolution. Given the variability of the measurements, however, we see no clear evidence of significant differences in center to edge spatial resolution among the three screens tested.

The relatively small (5.5% overall) reduction in spatial resolution as projected image size was reduced represents an apparent advantage of the laser projector over other displays. Further data are needed, however, to determine if this reduction in spatial resolution is significantly greater at the edge of the image.

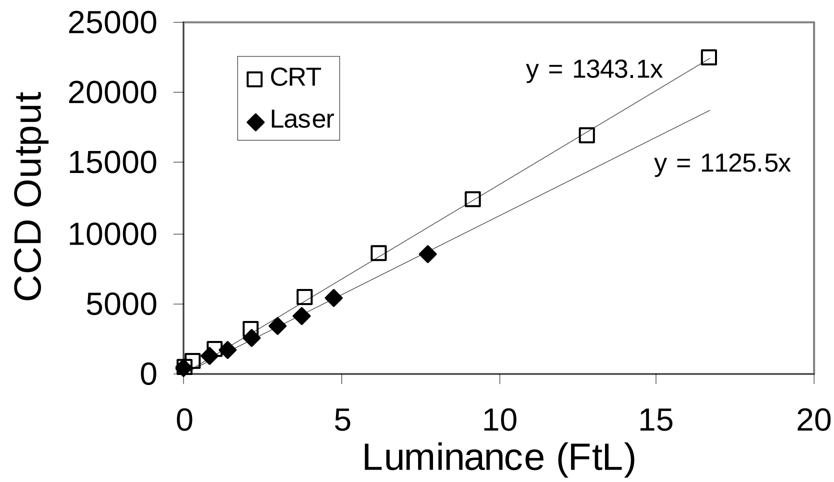

Figure 1. CCD output as a function of luminance measured with the spotmeter for both the laser projector and the CRT monitor.

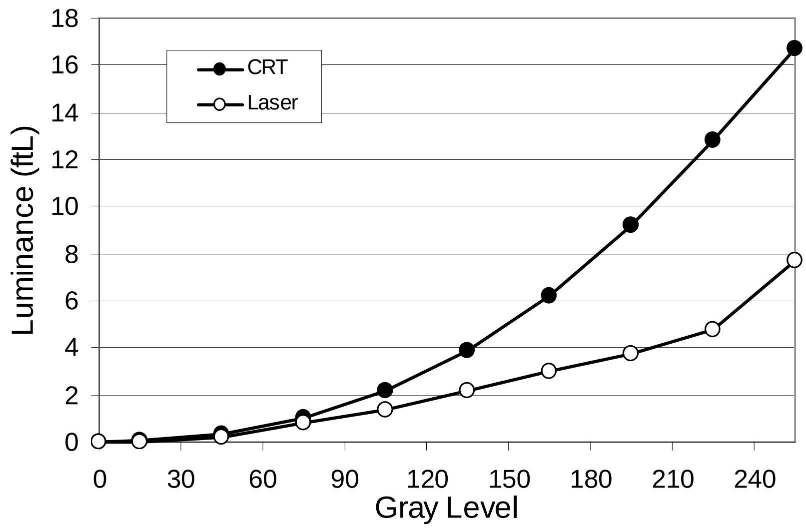

Figure 2. Gamma functions for the green channel of both the laser projector and the CRT monitor.

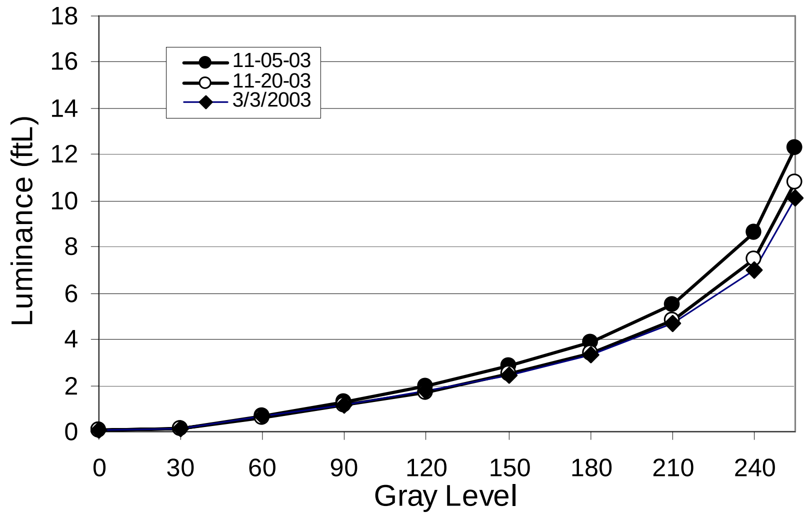

Figure 3. Gamma functions for the larger projector image size measured on each of three days.

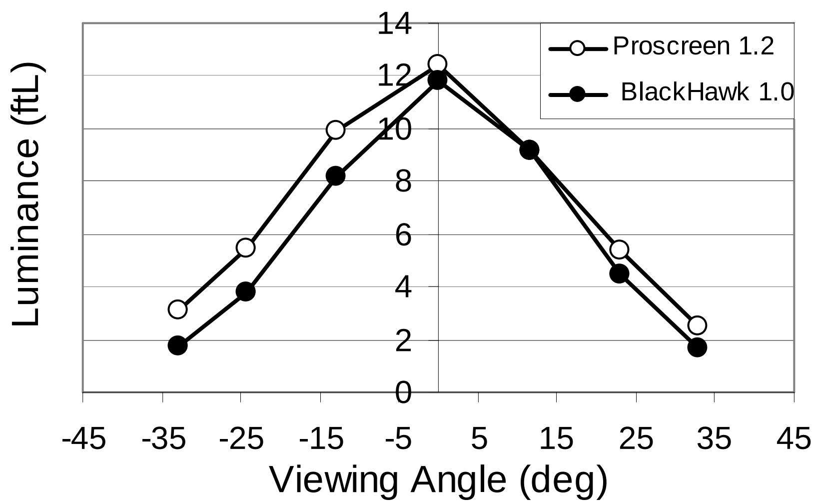

Figure 4. Screen luminance as a function of viewing angle from eye point.

Table 1. Comparison of Spatial Resolution at the Center and Edge of the Large Projected Image. Data are shown for both the ProScreen 1.2 and the Stewart Blackhawk Display Screens.

Screen	Pixel Format	Number of Resolved Lines (at 0.25 criterion)	Center to Edge Ratio
ProScreen 1.2 Center	5120x1024	2750 (11/05) 2279 (11/20)	1.07
ProScreen 1.2 Edge	5120x1024	2453 (11/05) 2266 (11/20)	
Blackhawk 1.0 Center	5120x1024	2337 (11/05) 2451 (11/20)	1.09
Blackhawk 1.0 Edge	5120x1024	2211 (11/05) 2189 (11/20)	
Jenmar Blackscreen Center	5120x1024	2355 (03/03)	1.06
Jenmar Blackscreen Edge	5120x1024	2215 (03/03)	

Table 2. Comparison of the Spatial Resolution of the Large and Small Projected Images Measured at both the Center and Edge of Each Image. Data are for the ProScreen 1.2 Display Screen Only.

Screen	Pixel Format	Number of Resolved Lines (at 0.25 criterion)	Large to small Ratio
ProScreen 1.2 Small-Center	5120x1024	2262 (11/20) 2751 (03/03)	1.01
ProScreen 1.2 Large-Center	5120x1024	2279 (11/20) 2789 (03/03)	
ProScreen 1.2 Small-Edge	5120x1024	2093 (03/03)	1.11
ProScreen 1.2 Large-Edge	5120x1024	2333 (03/03)	